July 1998

MONITORING AND EVALUATION OF SMOLT MIGRATION IN THE COLUMBIA BASIN VOLUME II

Evaluation of the 1996 Predictions of the Run-Timing Wild Migrant Subyearling Chinook in the Snake River Basin Using Program RealTime

Technical Report 1996

DOE/BP-91572-2

This report was funded by the Bonneville Power Administration (BPA), U.S. Department of Energy, as part of BPA's program to protect, mitigate, and enhance fish and wildlife affected by the development and operation of hydroelectric facilities on the Columbia River and its tributaries. The views of this report are the author's and do not necessarily represent the views of BPA.

This document should be cited as follows:

Townsend, Richard L., John R. Skalski, Dean Yasuda - University of Washington, Monitoring And Evaluation Of Smolt Migration In The Columbia Basin Volume II - Evaluation of the 1996 Predictions of the Run-Timing of Wild Migrant Subyearling Chinook in the Snake River Basin Using Program RealTime, Report to Bonneville Power Administration, Contract No. 1996BI91572, Project No. 199105100, 31 electronic pages (BPA Report DOE/BP-91572-2)

This report and other BPA Fish and Wildlife Publications are available on the Internet at:

http://www.efw.bpa.gov/cgi-bin/efw/FW/publications.cgi

For other information on electronic documents or other printed media, contact or write to:

Bonneville Power Administration
Environment, Fish and Wildlife Division
P.O. Box 3621
905 N.E. 11th Avenue
Portland, OR 97208-3621

Please include title, author, and DOE/BP number in the request.

MONITORING AND EVALUATION OF SMOLT MIGRATION IN THE COLUMBIA BASIN

VOLUME II

Evaluation of the 1996 Predictions of the Run-Timing of Wild Migrant Subyearling Chinook in the Snake River Basin Using Program RealTime

Prepared by:

Richard L. Townsend
John R. Skalski
Dean Yasuda

School of Fisheries
University of Washington
1325 Fourth Avenue, Suite 1820
Seattle, Washington 98101-2509

Prepared for:

U.S. Department of Energy
Bonneville Power Administration
Environment, Fish and Wildlife
P.O. Box 3621
Portland, OR 97208-3621

Project Number 91-051-00
Contract Number 96BI-91572

July 1998

Monitoring and Evaluation of Smolt Migration in the Columbia Basin

Other related publications, reports and papers available through the professional literature or from the Bonneville Power Administration (BPA) Public Information Center - CKPS-1, P.O. Box 3621, Portland, OR 97208.

1997

Townsend, R. L., D. Yasuda, and J. R. Skalski. 1997. Evaluation of the 1996 predictions of run timing of wild migrant spring/summer yearling chinook in the Snake River Basin using program RealTime. Technical Report (DOE/BP-91572-1) to BPA, Project 91-051-00, Contract 91-BI-91572.

1996

Townsend, R. L., P. Westhagen, D. Yasuda, J. R. Skalski, and K. Ryding. 1996. Evaluation of the 1995 predictions of run timing of wild migrant spring/summer yearling chinook in the Snake River Basin using program RealTime. Technical Report (DOE/BP-35885-9) to BPA, Project 91-051-00, Contract 87-BI-35885.

1995

Townsend, R. L., P. Westhagen, D. Yasuda, and J. R. Skalski. 1995. Evaluation of the 1994 predictions of the run-timing of wild migrant yearling chinook in the Snake River Basin. Technical Report (DOE/BP-35885-8) to BPA, Project 91-051-00, Contract 87-BI-35885.

1994

Skalski, J. R., G. Tartakovsky, S. G. Smith, P. Westhagen, and A. E. Giorgi. 1994. Pre-1994 season projection of run-timing capabilities using PIT-tag databases. Technical Report (DOE/BP-35885-7) to BPA, Project 91-051-00, Contract 87-BI-35885.

1993

Skalski, J. R., and A. E. Giorgi. 1993. A plan for estimating smolt travel time and survival in the Snake and Columbia Rivers. Technical Report (DOE/BP-35885-3) to BPA, Project 91-051-00, Contract 87-BI-35885.

Smith, S. G., J. R. Skalski, and A. E. Giorgi. 1993. Statistical evaluation of travel time estimation based on data from freeze-branded chinook salmon on the Snake River, 1982-1990. Technical Report (DOE/BP-35885-4) to BPA, Project 91-051-00, Contract 87-BI-35885.

Preface

Project 91-051 was initiated in 1991 in response to the Endangered Species Act (ESA) listings in the Snake River Basin of the Columbia River Basin. Primary objectives and management implications of this project include: (1) to address the need for further synthesis of historical tagging and other biological information to improve understanding and identify future research and analysis needs; (2) to assist in the development of improved monitoring capabilities, statistical methodologies and software tools to aid management in optimizing operational and fish passage strategies to maximize the protection and survival of listed threatened and endangered Snake River salmon populations and other listed and nonlisted stocks in the Columbia River Basin; (3) to design better analysis tools for evaluation programs; and (4) to provide statistical support to the Bonneville Power Administration and the Northwest fisheries community.

The following report addresses measure 4.3C of the 1994 Northwest Power Planning Council's Fish and Wildlife Program with emphasis on improved monitoring and evaluation of smolt migration in the Columbia River Basin. In this report, further application of using statistical program RealTime to predict the migration status and trend of the summer-outmigration of wild subyearling chinook at Lower Granite Dam is presented. It is hoped that making these real-time predictions and supporting data available on the Internet for use by the Technical Management Team (TMT) and members of the fisheries community will contribute to effective in-season population monitoring and assist in-season management of river and fisheries resources. Having the capability to more accurately predict smolt outmigration status should improve the ability to match flow augmentation to the migration timing of ESA listed and other salmonid stocks and should also contribute to the regional goal of increasing juvenile passage survival through the Columbia River system.

Abstract

In 1996, the University of Washington refined the application of program "RealTime" to improve the precision and accuracy of in-season predictions of the run-timing of the summer outmigration of wild Snake River subyearling chinook at Lower Granite Dam. The objective of the project was to predict and report in real-time the "percent run-to-date" and "date to specified percentiles" of the outmigration, based on the Fish Passage Center's (FPC) passage index. The algorithms were altered to better reflect the wild subyearling chinook outmigration timing and the nature of the passage index data. Basing predictions on historical years with similar flows were also investigated as a way to improve forecasting performance. Two groupings of the historical years were explored: one using all historical years with data available (1985-86, 1991-1995) and one that had years with environmental conditions during the outmigration period similar to 1996 (1993 and 1995). Flow level (high) was selected as an indicator of similar environmental conditions.

The mean absolute deviance (MAD) of the daily predicted outmigration-proportion from the actual outmigration-proportion was used as a measure of accuracy. The MAD's across the season in 1996 were approximately half that of the 1995 season MAD (5.42). Using all the historical years (AHY), the MAD was 3.06 across the season compared to 2.45 when only 1993 and 1995 were used as baseline (9395Y). The difference in performance during the first half of the outmigration between the AHY grouping (MAD = 1.98) and the 9395Y grouping (MAD = 3.17) is small, though drastically improved over 1995's first half prediction performance (MAD = 7.63). MAD's for the last half of the outmigration season of 1995 and the 1996 AHY grouping are similar (1995 MAD = 3.13, 1996 AHY MAD = 3.55), with improvement in prediction displayed by the 9395Y grouping (MAD = 2.12).

Executive Summary

1996 Objectives

1. Refine application of program RealTime to improve precision and accuracy of in-season predictions of the run-timing of the summer-outmigration of Snake River subyearling chinook at Lower Granite Dam.
2. Predict and report in real-time the “percent run-to-date” and “date to specified percentiles” of wild subyearling chinook outmigration at Lower Granite Dam, based on the Fish Passage Center’s (FPC) passage index[1].
3. Post on-line Internet-based predictions on outmigration status and trends to improve in-season population monitoring information available for use by the Technical Management Team and the fisheries community to assist river management.

Accomplishments

Some adjustments had to be made to program RealTime algorithms in 1996, following 1995 when the program was first applied to wild subyearling chinook passage indices at Lower Granite Dam. The equations were altered to reflect the wild subyearling chinook outmigration timing and the nature of the passage index data. Basing predictions on historical years with similar flows were also investigated as a way to improve forecasting performance. Both objectives were accomplished for the Lower Granite Dam passage index provided by the Fish Passage Center. On-line run-timing predictions were provided via the Internet to the fisheries community throughout the smolt outmigration.

Findings

The 1996 prediction performance was significantly improved over the program’s performance in 1995. Further investigation into the Fish Passage Center’s historical database of the wild subyearling chinook passage index at Lower Granite Dam provided additional historical years for use

1. The FPC wild subyearling chinook fish passage indices at Lower Granite Dam are a mixture of wild fall chinook and small spring/summer chinook salmon, but are presumed to represent primarily fall chinook passage. Prior to 1993, some unknown faction of hatchery produced spring/summer chinook were likely also included in the index. From 1993 on, all hatchery-produced chinook released in the Snake River Basin have been fin-clipped to confirm their origin and distinguish them from ESA listed stocks.

as a basis for determining the subyearling outmigration distribution. Two groupings of historical years were explored: one using all historical years with data available (1985-86, 1991-1995) and one that had years with environmental conditions during the outmigration period similar to 1996 (1993 and 1995). Flow level (high) was selected as an indicator of similar environmental conditions.

The mean absolute deviance[1] (MAD) of the daily predicted outmigration-proportion from the actual outmigration-proportion as a measure of accuracy. The MAD's across the season in 1996 were approximately half that of the 1995 season MAD (5.42). Using all the historical years (AHY), the MAD was 3.06 across the season compared to 2.45 when only 1993 and 1995 were used as baseline (9395Y). The difference in performance during the first half of the outmigration between the AHY grouping (MAD = 1.98) and the 9395Y grouping (MAD = 3.17) is small, though drastically improved over 1995's first half prediction performance (MAD = 7.63), and likely due to the weighting of smolt seen prior to 1 June less those observed after 1 June in the outmigration timing distribution. MAD's for the last half of the outmigration season of 1995 and the 1996 AHY grouping are similar (1995 MAD = 3.13, 1996 AHY MAD = 3.55), with improvement in prediction displayed by the 9395Y grouping (MAD = 2.12). The better last half season performance of the 9395Y grouping may be due more to the exclusion of the 1985 and 1986 outmigration data than the fact that 1993 and 1995 were high flow years. Both 1985 and 1986 had large passage indices, but the smolt monitoring sampling program ended on July 23rd in 1985 and July 24th in 1986, likely well before the characteristic protracted outmigration of subyearling chinook was completed at Lower Granite Dam. The exclusion also created noticeably smaller daily confidence intervals estimated by program RealTime for the 9395Y grouping.

Management Implications

The ability to accurately predict the outmigration status of the wild subyearling chinook salmon population at different locations in the Federal Columbia River Power System (FCRPS) can provide valuable information to assist water managers in optimizing operational and fish passage strategies to maximize benefits to smolt survival. As ambient river conditions effecting

1. Mean absolute deviance is the average absolute difference between the predicted proportion and the observed proportion of the outmigration distribution, calculated over the days in the outmigration.

smolt survival change in-season, it is important for water managers to be able to assess the risks to the migrating populations so that adequate actions to protect weak, listed and endangered stocks can be taken. Providing run-timing predictions in real-time contributes to effective monitoring, evaluation and adaptive management and improves the information available to water managers and the fisheries community to better manage river and fisheries resources.

Recommendations

Results from the 1996 prediction of run-timing of the summer-outmigration of Snake River wild subyearling chinook at Lower Granite Dam suggest improvements that can be made to the RealTime program in the future. Both groupings of years proved to be fairly equivalent in prediction accuracy, providing an improved forecast and smaller confidence intervals over the 1995 predictions. The advantage provided by using only similar-flow years over using all the historical years available as a baseline was small, decreasing the prediction MAD by only 0.51 across the season and by 1.43 for the last half of the season. The increase in prediction accuracy is further mitigated by the fact that it appears to be the exclusion of the oldest historical data which provided the better forecast rather than the inclusion of only similar-flow years. Additionally, there has not been any research showing conclusive evidence of a flow-travel time relationship to Lower Granite Dam for the wild subyearling chinook (Connor 1994b and 1996; Giorgi and Schlechte 1997; OWICU 1996; Smith et al. 1997). Therefore, it is recommended that all of the more recent historical years (1991-1996) be used in the 1997 RealTime forecasts.

Acknowledgments

We wish to express thanks to the many fisheries agencies, Tribes and other institutions that have expended considerable resources in the generation, assembly, analysis and sharing of Columbia River biological, hydrologic, operational and other related information. Deserving particular thanks are the staff of the agencies and Tribes responsible for conducting the annual Columbia River Smolt Monitoring Program, the Fish Passage Center and the Pacific States Marine Fisheries Commission PIT-Tag Information System (PTAGIS) primary database centers for providing timely in-season access to fish passage and PIT-tag information and the University of Washington second-tier database DART (Data Access in Real Time) information system which receives, processes and provides access to biological, hydrologic and operational information via the Internet.

Special appreciation is extended to Judy Cress and Peter Westhagen of the School of Fisheries at the University of Washington for providing critical data management and computer programming support, and to Dr. Al Giorgi for his guidance on biological characteristics of the wild subyearling chinook and thoughtful reviews of early drafts of this manuscript.

Funding support for this work came from the Pacific Northwest region's electrical ratepayers through the Columbia River Fish and Wildlife Program administered by the Bonneville Power Administration.

Table of Contents

List of Figures

List of Tables

Table **Page**

Introduction

Regulating the timing and volume of water released from storage reservoirs (often referred to as flow augmentation) has become a central mitigation strategy for improving downstream migration conditions for juvenile salmonids in the Columbia River Basin. Threatened and endangered salmon stocks have received increased priority with regard to the timing of this flow augmentation, particularly in the Snake River. The optimum is to release water from the storage reservoirs at times when the listed stocks are in geographic locations where they encounter the augmented flow. The success of the flow augmentation, in turn, depends on releasing reservoir waters when and where wild smolt will benefit the most. This requires the ability to predict in real-time the status and trend in the outmigration timing.

Beginning in 1993, a task was initiated under this project to develop and provide real-time analyses of smolt outmigration dynamics for ESA listed stocks and other runs-at-large for the Snake and Columbia Rivers. Program RealTime, a statistical software program for predictions of run-timing (Skalski et al. 1994), was developed to take advantage of historical data to predict the proportion of a particular population that had arrived at an index site in real-time and to forecast elapsed time to some future percentile in a migration. The initial application of program RealTime used PIT-tag detections at Lower Granite Dam to predict the outmigrations of Snake River wild yearling spring/summer chinook at Lower Granite Dam in real-time. Since 1994, program RealTime (PIT Forecaster) has been used to make daily predictions of the “percent run-to-date” and “date to specified percentiles” for a number of individual streams included in the National Marine Fisheries Service (NMFS) ecological significant unit (ESU) for Snake River wild yearling spring/summer chinook (Townsend et al. 1995, 1996a, 1997).

In addition, in 1995, the feasibility of using program RealTime to predict the general status and trend of the summer outmigrations of Snake River wild subyearling chinook at Lower Granite Dam was investigated (Townsend et al. 1996b). While information on the migrational characteristics of wild subyearling chinook are more limited than that of the wild spring/summer chinook in the Snake River system, some data on migrational timing have recently been collected and reported (Connor et al. 1993, 1994a, 1994b, 1996; Giorgi and Schlechte 1997; OWICU 1996;

Smith et al. 1997). Because only minimal PIT-tagging of naturally-produced wild fall subyearling chinook occurs in the Snake River system due to low stock abundance, program RealTime was altered to use the daily passage index of wild subyearling chinook Lower Granite Dam provided by the Fish Passage Center(FPC) rather than Lower Granite Dam PIT-tag detections, to characterize run-timing of summer migrants. The program's algorithms were adjusted, as the migrating behavior of subyearling chinook differs from spring/summer yearling chinook (Nelson et al. accepted; Rondorf et al. 1993, 1994a, 1994b, 1996; Connor et al. 1992, in-preparation-a,b,c; Garcia et al. in preparation; Tiffan et al. in preparation-a,b).

This report presents a post-season analysis of the results from the second year of using program RealTime for in-season prediction of the run-timing of the summer outmigration of wild subyearling chinook salmon from the Snake River system. Observed 1996 data were compared to the predictions made by RealTime for the outmigration of wild subyearling chinook observed at Lower Granite Dam throughout the season. Additional graphical reports for selected days throughout the 1996 season are available on the World Wide Web at address *http://www.cqs.washington.edu/crisprt/season96.html*.

Methods

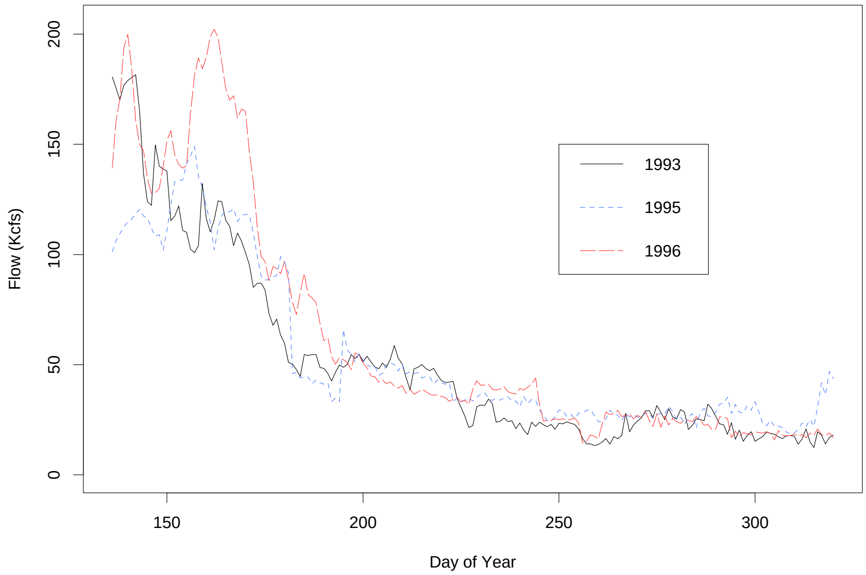
Description of Data

The outmigration of wild subyearling chinook from the passage indices at Lower Granite Dam were obtained from the Fish Passage Center (FPC). The FPC wild subyearling chinook fish passage indices at Lower Granite Dam represents a mixed race population comprised of wild fall chinook and small spring/summer chinook salmon, but are presumed to represent primarily fall chinook passage. Further investigation of the FPC historical database showed that 1985, 1986, 1991 and 1992 met the RealTime criteria for potential reference years, in addition to the two years, 1993 and 1994, that were used by the program last year. One caveat to this information is that at the beginning of the wild subyearling fall chinook migration in May, it is problematic to differentiate subyearling fall chinook from small wild spring/summer chinook without sacrificing some fish. This becomes less of an issue towards the end of the year, but can make a difference in the shape of the timing distribution at the beginning of the subyearling fall chinook outmigration (Connor et al. 1993). Because of this situation, the timing distribution of the smolt observed prior to 1 June was deemed too inconsistent for estimation purposes, and are therefore not used in the 1996 predictions.

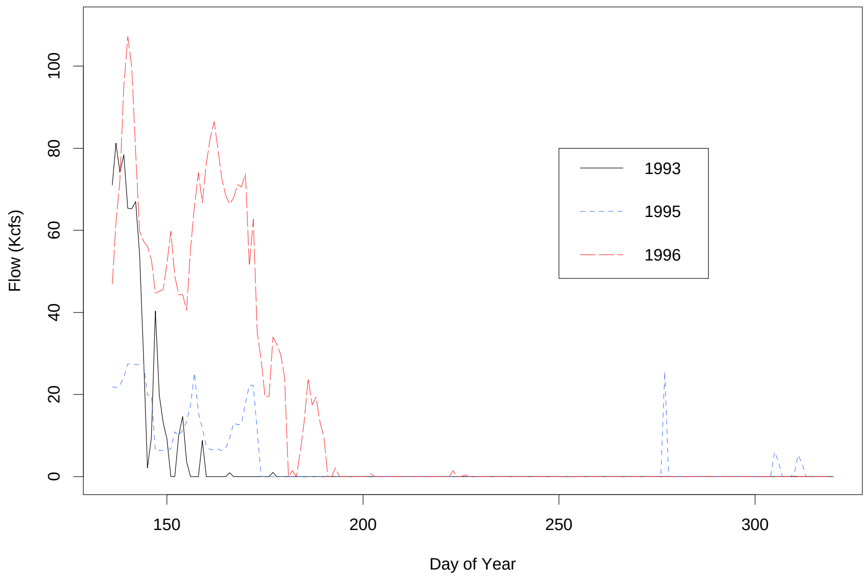
Two other sources of variance identified in the post-season 1995 RealTime report were the amounts of spill and flow experienced by the fish. While flow has not been shown conclusively to have an impact on subyearling chinook travel time above Lower Granite Dam (Connor 1994b and 1996; Giorgi and Schlechte 1997; Smith et al. 1997), it may represent an indicator of similar environmental conditions experienced by the smolt (for example, temperature, flow and turbidity are all highly correlated). To test the theory that flow, or something correlated with flow, has an impact on wild subyearling outmigration timing, a separate “similar flow-years” group was created in addition to basing predictions on all historical years (AHY) available. The 1996 season was predicted to be a “high flow” year, similar to 1993 and 1995. Consequently 1993, 1995 were treated as an alternative grouping (9395Y) of historical years used in forecasting run timing. All three years were fairly close in flow and spill (Figure 1). Spill generally did not occur during the fall outmigration (after 1 June), reducing the variance contributed by the inflation of the observed outmigration numbers to account for the probability of smolt passing Lower Granite Dam through the spillways.

Figure 1: The amount of (a) outflow and (b) spill at Lower Granite Dam for 1993, 1995 and 1996.

a.



b.



Prediction Models

The Least Squares (LS) method is a variation of the prediction method used for the for the spring/summer wild yearling chinook outmigration, incorporating release-recapture information and a measure of the age of the run (number of days from the start of the outmigration to the present, weighted by the number of fish observed per day) into its prediction algorithm. This approach has been shown to be more accurate and provides a more robust predictor than least-squares or simple release-recapture alone.

Least-Squares (LS) Algorithm

For a given day in the run, the LS algorithm computes the predicted percentage ($\hat{p}$) of the out-migration by finding the value of $\hat{p}$ that minimizes the estimated error according to historical run data. The $\hat{p}$ error is a weighted combination of the least-squares (LS) error, the release-recapture (RR) error, and the age-of-run (AR) error. Weighting depends on the age of the run and the quality of the historic data for the given stream. In the 1994 post-season analysis of the RealTime program using PIT tagged smolt, the release-recapture method was shown to be a better predictor at the beginning of a run, deteriorating as time progressed. On the other hand, the least-squares method started poorly, but became a better predictor as the run progressed. To combine these two methods, the release-recapture algorithm prediction is heavily weighted initially, with weight shifted to the LS method over time. The initial weighting of the RR error also depends on the consistency of release-recapture history for the selected stream or river composite.

Least-Squares (LS) Error

The least-squares error (LSE) for each $\hat{p}$ is summed over the historical years for which data are available. The current run is smoothed using 3, 5-day smoothing passes to filter out statistical randomness. The same smoothing is done to the initial $\hat{p}$ percent of each historical year. Each outmigration pattern is divided into 100 equal portions and the slopes over each corresponding interval are computed. The sum of squares for a prediction compares the slopes for the current year (s_{oj}) versus the respective slopes for the initial $\hat{p}$ percent of the historical years ($s_{ij\hat{p}}$). The total squared error for each predicted percentage of outmigration $\hat{p}$ is calculated according to the formula:

$$LSE(\hat{p}) = \sum_{i=1}^{n} \sum_{j=0}^{\hat{p}} (s_{oj} - s_{ij})^2 w_{ij} \tag{1}$$

where s_{oj} = observed slope at the *j*th percentile ($j = 0, ..., p$) for the current year of prediction,

s_{ij} = slope at the *j*th percentile ($j = 0, ..., 100$) for the first *p* percent of the *i*th historical year ($i = 1, ..., n$), and

w_{ij} = weight for the *j*th percentile for the *i*th historical year.

For example, letting $\hat{p}$ = 30%, the present run will be compared to the first 30% of the outmigration for each historical year. Similar calculations are performed for each percentage from 0 to 100 percent. The percentage that minimizes the sum of squares (Eq. 1) is the best prediction for the current outmigration timing according to the LS algorithm. The weighting factor is included to more evenly distribute the squared error contribution throughout the outmigration distribution. The weights are:

$$w_{ij} = \frac{D_{oj} + D_{ij}}{R_o + R_i}$$

where D_{oj} = estimated number of days between the (*j*-1) and *j*th percentile for the present year,

D_{ij} = number of days between the (*j*-1) and *j*th percentile for the *i*th historical year ($i = 1, ..., n$),

R_o = range in days of the current observed outmigration, and

R_i = range in days of the ith historical year outmigration ($i = 1, ..., n$).

The effect of w_{ij} is to give more weight to the errors generated in the tails of the distribution, where the slopes tend to be flat and the number of days between each percentile point are high. Less weight is given to the mid-season, when large numbers of fish detected on a daily basis will create a steep slope in the cumulative distribution. The total sum of the weights adds to one.

Release-Recapture (RR) Error

For spring/summer PIT-tagged smolt, the Release-Recapture method made predictions of run timing by using the total recapture proportion observed in a previous year and then assuming that same proportion to be observed again in the present year. Wild subyearling chinook present the problem that the total "released" is not known. Instead, the total number observed passage index the previous year is used as an estimate of the total passage index predicted for the present year (Table 1) (i.e. total previous year = number "released" this year). The predicted percent of the run is calculated according to the formula

$$RR = \frac{x_d}{N} \tag{2}$$

where

RR	= estimated proportion of the outmigration passed on day d,
x_d	= total observed smolt to day *d*, and
N	= total number of smolt observed the previous year.

RealTime then evaluates each possible percentage $\hat{p}$ (0 to 100) of the outmigration proportion at Lower Granite Dam by calculating an associated Release-Recapture error (RRE). The RRE($\hat{p}$) is the ratio of the predicted RRE($\hat{p}$) and each percentage $\hat{p}$ of the outmigration distribution:

$$RRE(\hat{p}) = \begin{cases} \dfrac{\hat{p}}{RR} & if \quad \hat{p} > RR \\ \dfrac{RR}{\hat{p}} & if \quad \hat{p} < RR \\ 1 & if \quad \hat{p} = RR \end{cases} \tag{3}$$

The prediction $\hat{p}$ is assigned the least amount of error (*RRE*($\hat{p}$) = 1) when it is equal to $RR(\hat{p})$ and more error (*RRE*($\hat{p}$) > 1) the further $\hat{p}$ is from $RR(\hat{p})$.

Table 1: The total passage index numbers of wild subyearling chinook salmon detected at Lower Granite Dam, 1985-86, 1991-1996, June 1 and after.

Year	Number observed
1985	43,774
1986	54,942
1991	13,672
1992	5,744
1993	16,620
1994	6,765
1995	26,046
1996	17,548

Age-of-Run (AR) Error

For the age-of-the-run method, the prediction $\hat{p}$ was the historical proportion observed on a given day of outmigration for a specified historical year.

$$\hat{p} = p_{yd} \qquad (4)$$

where p_{yd} = proportion of outmigration passed on day *d* for historical year *y*.

For a given day of run, the proportion predicted is given by the proportion observed in the index year on that day of the run (e.g. for a run estimated to be in its 15th day, the percentage passed by day 15 in a historical run is the estimated present percentage observed). This method was very unstable as historical patterns did not support a day-for-day matching in smolt migration through the years. On the other hand, the mean age of the run, weighted by the cumulative number of fish observed per day, appeared to offer further information and be more robust year to year. The mean fish-run-age (MFRA) is calculated for each *p* of the last historical outmigration and the present run by

$$MFRA(p) = \frac{\sum_{d=1}^{n} [fish_d \times (n + 1 - d)]}{\sum_{d=1}^{n} fish_d} \tag{5}$$

where:

$fish_d$ = number of fish observed on day d,

n = total number of days until the cumulative proportion p of the total smolt outmigration has been observed.

The present year's MFRA is matched to each historical year's MFRA. The historical observed p corresponding to the matching MFRA is the predicted p_{AR} from that year.

The Age-of-Run error (ARE) associated with this prediction is the ratio of the present run mean fish-run-age ($MFRA_{AR}$) and the predicted percentage $\hat{p}$ mean fish-run-age ($MFRA_{\hat{p}}$):

$$ARE(\hat{p}) = \begin{cases} \dfrac{MFRA_{\hat{p}}}{MFRA_{AR}} & if \quad MFRA_{\hat{p}} > MFRA_{AR} \\ \dfrac{MFRA_{AR}}{MFRA_{\hat{p}}} & if \quad MFRA_{\hat{p}} < MFRA_{AR} \\ 1 & if \quad MFRA_{\hat{p}} = MFRA_{AR} \end{cases} \tag{6}$$

This gives the prediction from the AR algorithm the least amount of error, with more error the further $\hat{p}$ is from p_{AR}.

Calculation of the Total Error

An error is computed for each $\hat{p}$ (0-100) by combining the three algorithms by:

$$Err(\hat{p}) = \left(1 + \frac{LSE(\hat{p})}{LSE(\hat{p}) \times MFRA + 200}\right) \times \tag{7}$$

$$\left.\left[\frac{50}{\left(MFRA + \frac{RR}{2}\right)^2} \times RRE(\hat{p})\right]^2\right) \times \left(1 + \frac{ARE(\hat{p}))}{50}\right)$$

where:

- $ARE(\hat{p})$ = age-of-run error for $\hat{p}$ from Eq. 6,
- $LSE(\hat{p})$ = least squares error for $\hat{p}$ from Eq. 1,
- $MFRA$ = mean fish-run-age for the present run from Eq. 5,
- RR = predicted proportion of observed present smolt outmigration from Eq. 2, and

Calendar Date

- $RRE(\hat{p})$ = release-recapture error for $\hat{p}$ from Eq. 3.

The MFRA in Eq. 6 also serves the purpose of shifting the weighting of the errors from the release-recapture algorithm to the least-squares algorithm as the age of the run increases. The constants were found by heuristically adjusting the equation and observing program prediction performance for historical outmigration data. The program selects the $\hat{p}$ with the minimal calculated error.

Calculation of Performance of Program RealTime Across the Season

The results presented in Table 2 contain the mean absolute deviance (MAD) of the LS prediction for the observed 1996 data. The MAD is calculated by the formula:

$$MAD = \frac{\sum_{i=1}^{n} \left|\hat{p}_i - p_i\right|}{n} \tag{8}$$

where $\hat{p}_i$ = predicted cumulative percentage of run completed for day i,

p_i = observed cumulative percentage of run completed for day i, and

n = total number of days in run for 1994 season.

The methods are compared three ways: the MAD over the entire run, the MAD over the first half of the run (i.e. cumulative run to the 50%), and the MAD over the last half of the run.

Results

Two groupings of historical years were investigated for basis of the 1996 predictions, both groupings showing significant improvement over the program's performance in 1995. One group used all historical years (AHY) available data (1985-86, 1991-1995) and the other consisted of years with high flow (1993 and 1995) during the outmigration similar to 1996 (9395Y). A graphical comparison of the daily predictions using the AHY grouping (Figure 2[1]) and the 9395Y grouping (Figure 3) and their 95% confidence intervals against the observed run for the year are very similar. The MAD's across the season in 1996 were approximately half of the 1995 season MAD (5.42) for both of the approaches to grouping historical years (AHY MAD = 3.06, 9395Y MAD = 2.45). The difference in performance during the first half of the outmigration between the AHY grouping (MAD = 1.98) and the 9395Y grouping (MAD = 3.17) is small, though drastically improved over 1995's first half prediction performance (MAD = 7.63). MAD's for the last half of the outmigration season of 1995 and the 1996 AHY grouping are similar (1995 MAD = 3.13, 1996 AHY MAD = 3.55), with the more accurate prediction displayed by the 9395Y grouping (MAD = 2.12).

1. Graphical reports for selected days throughout the 1996 season are available on the World Wide Web at address http://www.cqs.washington.edu/crisprt/season96.html

Table 2: Comparison of mean absolute deviances (MAD) for Lower Granite Dam passage indices for the 1995 and 1996 wild subyearling chinook daily outmigration predictions.

period	1995 MAD	1996 MAD all historical years	1996 MAD only 1993 and 1995 years used
entire outmigration season	5.42	3.06	2.45
first 50% of season	7.63	1.98	3.17
last 50% of season	3.13	3.55	2.12

Timing plots of the historical years of subyearling chinook outmigration show large variation from year to year in the mid-outmigration distribution (Figure 4). Beginning and ending dates are within a couple days of each other because of the sampling time-frame used by FPC.

Figure 2: Daily outmigration status predictions and 95% confidence intervals compared to the observed wild subyearling chinook salmon outmigration for 1996 at Lower Granite Dam, using all historical data available (AHY).

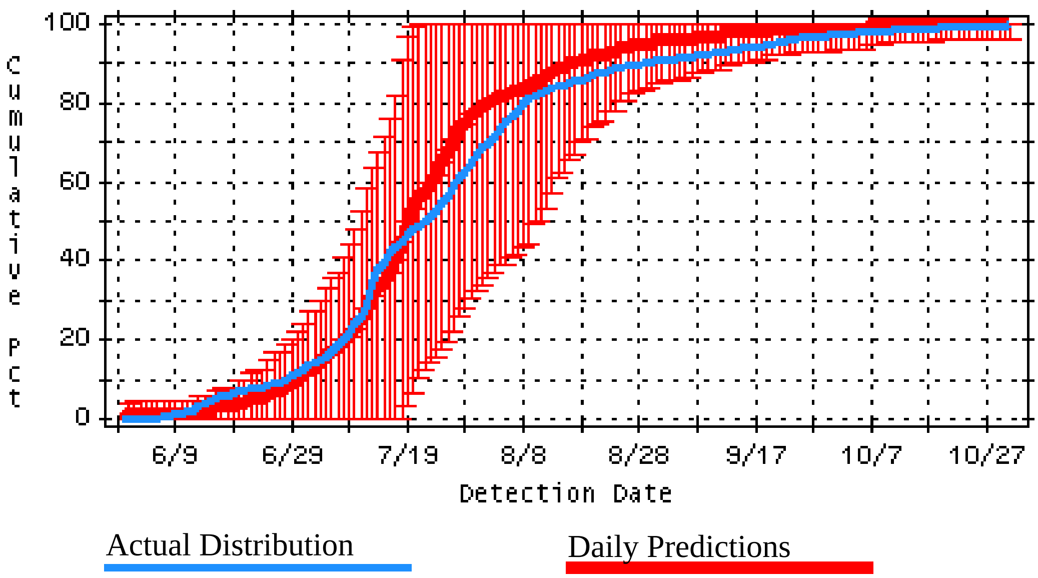


Figure 3: Daily outmigration status predictions and 95% confidence intervals compared to the observed wild subyearling chinook salmon outmigration for 1996 at Lower Granite Dam, using historical data from 1993 and 1995 only (9395Y).

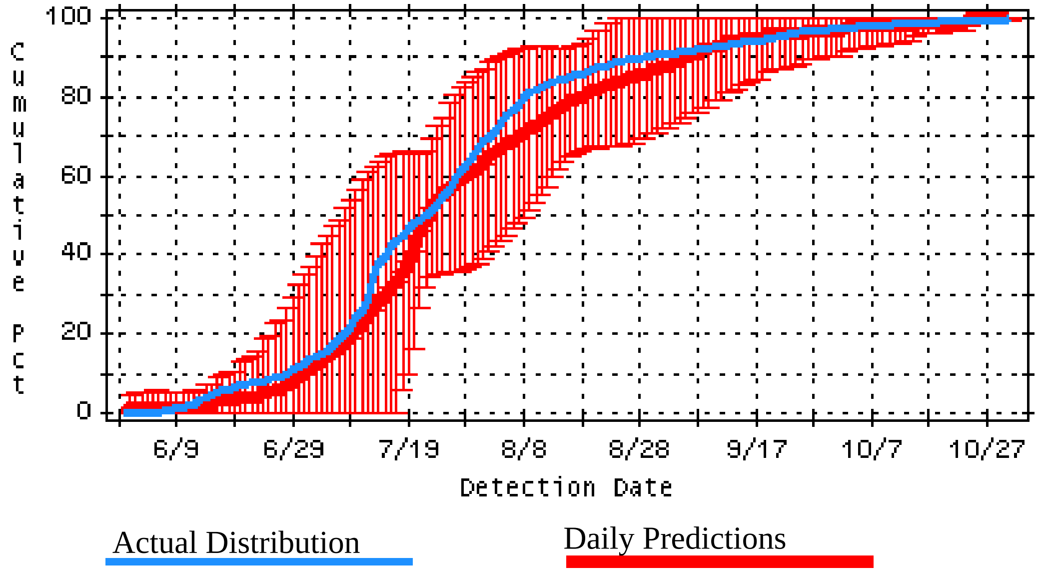
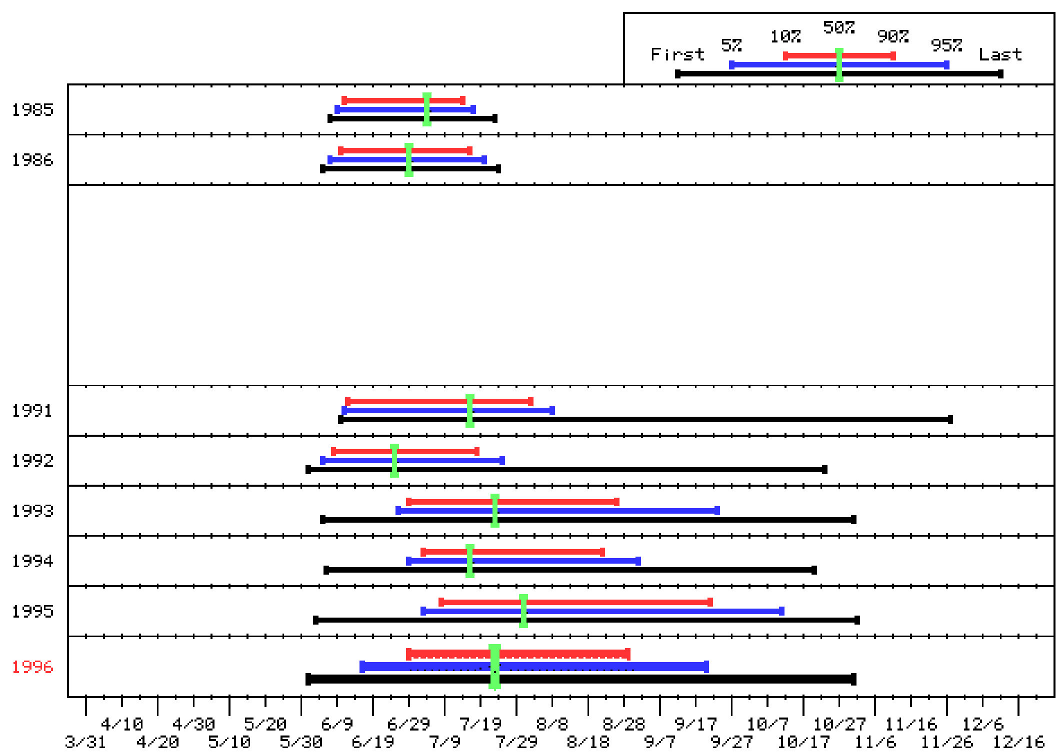


Figure 4: Timing plots of passage dates (0%, 10%, 50%, 90% and 100%) at Lower Granite Dam for wild Snake River subyearling chinook salmon smolt passage indices for all years that data were available.

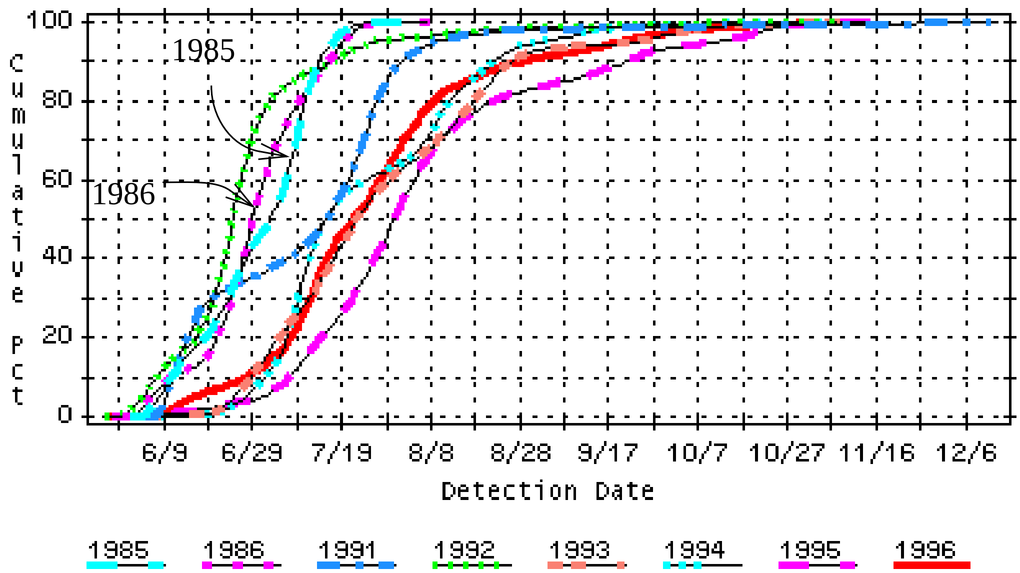


Discussion

The improvement in performance during the first half of the outmigration for both the AHY grouping and the 9395Y grouping over the 1995 RealTime results is reasonably due to the alteration in program RealTime's algorithms to "start" the wild subyearling outmigration with the first smolt observed 1 June or after. Prior to 1 June, the sampling rates at Granite Dam are low, during which a few smolt detections tend to be adjusted to represent a relatively large number of fish passing through Lower Granite at the time. In addition, some of these early arrivals may be small wild spring/summer chinook, which cannot be visually differentiated from wild subyearling chinook (Connor et al. in-preparation-a, OWICU 1996). The proportion of yearling to subyearling in this mixture varies from year to year. This combination tends to give the beginning tail of the outmigration distribution a good deal of annual variation. Smolt observed after 1 June are more likely wild subyearling chinook vice small spring/summer yearling chinook.

The better last half season-performance of the 9395Y grouping may be due more to the exclusion of the 1985 and 1986 outmigration data than the fact that 1993 and 1995 were high flow years (Figure 4). Both 1985 and 1986 had large passage indices and an indicated short outmigration time, but the smolt monitoring sampling program at Lower Granite Dam ended on July 23rd in 1985 and July 24th in 1986, likely well before the characteristic protracted outmigration of subyearling chinook was completed. The exclusion of these two years that hit the 100% outmigration status so quickly also created noticeably smaller daily confidence intervals estimated by program RealTime for the 9395Y grouping as compared to the AHY grouping. The graph of cumulative outmigration timing distribution (Figure 5) shows that 1991 and especially 1994 have similar cumulative distributions to 1996, and their inclusion would have further enhanced predictive performance. The effort to "pick and choose" similar historical years is a subjective decision. Furthermore, while migrational timing, duration, magnitude and survival have been shown to be influenced by environmental conditions such as flow, temperature and turbidity (Connor 1994b and 1996; Giorgi and Schlechte 1997; OWICU 1996; Smith et al. 1997), there has not been any consistent research results showing conclusive evidence of a flow-travel time relationship for wild subyearling chinook to Lower Granite Dam. Therefore, it is recommended for future years to use all of the more recent historical data agreed upon by OWICU (1996) as reliable in basing our outmigration forecasts. The years 1991-1996 are more similar in not only biological regimes, but also in monitoring methodology, record-keeping and scientific terminology, all of which are sources of unintended variation confounding the search for an annual outmigration pattern.

Figure 5: Wild Snake River subyearling chinook salmon historical cumulative percentage passage dates for 1985-86, 1991-96.



Literature Cited

Connor, W.P., H. Burge and R. Bugert. 1992. Migration timing of natural and hatchery fall chinook in the Salmon River Basin. Pages 46-56 in Passage and survival of juvenile chinook salmon migrating from the Snake River Basin. Proceedings of a technical workshop. Prepared by the Idaho Chapter of the American Fisheries Society, Idaho Water Resources Institute, University of Idaho Cooperative Fish and Wildlife Research Unit and the Western Division of the American Fisheries Society.

Connor, W.P., H.L. Burge and W.H. Miller. 1993. Rearing and emigration of naturally produced Snake River fall chinook salmon juveniles. Pages 81-116 *In* D.W. Rondorf and W.H. Miller, editors. Identification of the spawning, rearing and migratory requirements of fall chinook in the Columbia River Basin. 1991 Annual Report to Bonneville Power Administration (DOE/BP-21708-1), Contract DEAI79-91BP21708, Portland, Oregon. (Available from Bonneville Power Administration, Division of Fish and Wildlife, P.O. Box 3621, Portland, OR. 97283-3621.)

Connor, W.P., H.L. Burge and W.H. Miller. 1994a. Rearing and emigration of naturally produced Snake River fall chinook salmon juveniles. Pages 92-119 *In* D.W. Rondorf and W.H. Miller, editors. Identification of the spawning, rearing and migratory requirements of fall chinook in the Columbia River Basin. 1992 Annual Report to Bonneville Power Administration (DOE/BP-21708-2), Contract DEAI79-91BP21708, Portland, Oregon. (Available from Bonneville Power Administration, Division of Fish and Wildlife, P.O. Box 3621, Portland, OR. 97283-3621.)

Connor, W.P., H.L. Burge, D. Steele, C. Eaton and R. Bowen. 1994b. Rearing and emigration of naturally produced Snake River fall chinook salmon juveniles. Pages 41-73 *In* D.W. Rondorf and K.F. Tiffan, editors. Identification of the spawning, rearing and migratory requirements of fall chinook in the Columbia River Basin. 1993 Annual Report to Bonneville Power Administration (DOE/BP-21708-3), Contract DEAI79-91BP21708, Portland, Oregon. (Available from Bonneville Power Administration, Division of Fish and Wildlife, P.O. Box 3621, Portland, OR. 97283-3621.)

Connor, W.P., H.L. Burge, R.D. Nelle, C. Eaton and R. Waitt. 1996. Rearing and emigration of naturally produced Snake River fall chinook salmon juveniles. Pages 44-63 *In* D.W. Rondorf and K.F.Tiffan, editors. Identification of the spawning, rearing and migratory requirements of fall chinook in the Columbia River Basin. 1994 Annual Report to Bonneville Power Administration (DOE/BP-21708-4), Contract DEAI79-91BP21708, Portland, Oregon. (Available from Bonneville Power Administration, Division of Fish and Wildlife, P.O. Box 3621, Portland, OR. 97283-3621.)

Connor, W.P., and several co-authors. In preparation-a. Stock and race identification of subyearling chinook salmon in the Snake River. A manuscript to be submitted to the North American Journal of Fisheries Management in 1996.

Connor, W.P., and several co-authors. In preparation-b. Snake River fall chinook salmon early life history: past and present. A manuscript to be submitted to the North American Journal of Fisheries Management in 1996.

Connor, W.P., and several co-authors. In preparation-c. Fall chinook salmon spawning habitat availability in the Snake River. A manuscript to be submitted to the North American Journal of Fisheries Management in 1996.

Garcia, A.P., and several co-authors. Fall chinook salmon spawning ground surveys in the Snake River. A manuscript to be submitted to the North American Journal of Fisheries Management in 1996.

Giorgi, A. E., and J. W. Schlechte. 1997. An evaluation of the effectiveness of flow augmentation in the Snake River, 1991-1995. Phase I Final Report (DOE/BP-24576-1) to Bonneville Power Administration 95-070-00, Contract DE-AC79-92BP24576. 47p. plus appendices. (Available from Bonneville Power Administration, Division of Fish and Wildlife, P.O. Box 3621, Portland, OR. 97283-3621.)

Giorgi, A. E., L. C. Stuehrenberg, D. R. Miller and C. W. Sims. 1985. Smolt passage behavior and flow-net relationship to the forebay of John Day Dam. Final Res. Rep. (DOE/BP-39644-1) to Bonneville Power Administration, Project 82-008, Contract DE-AI79-84BP39644. 184 p. (Available from Bonneville Power Administration, Division of Fish and Wildlife, P.O. Box 3621, Portland, OR. 97283-3621.)

Nelson, W.R., L.K. Freidenburg and D.W. Rondorf. Accepted. Swimming behavior and performance of emigrating subyearling chinook salmon. Transactions of the American Fisheries Society.

OWICU. 1996. Memorandum dated June 3, 1996, prepared by technical staffs of the Columbia River salmon management agencies to Implementation Team: Review of Fall Chinook Juvenile Migration Data. 19 p.

Rondorf, D.W., and W.H. Miller, editors. 1993. Identification of the spawning, rearing and migratory requirements of fall chinook salmon in the Columbia River basin. 1991 Annual Report to Bonneville Power Administration (DOE/BP-21708-1), Contract DEAI79-91BP21708, Portland, Oregon. (Available from Bonneville Power Administration, Division of Fish and Wildlife, P.O. Box 3621, Portland, OR. 97283-3621.)

Rondorf, D.W., and W.H. Miller, editors. 1994a. Identification of the spawning, rearing and migratory requirements of fall chinook salmon in the Columbia River basin. 1992 Annual Report to Bonneville Power Administration (DOE/BP-21708-2), Contract DEAI79-91BP21708, Portland, Oregon. (Available from Bonneville Power Administration, Division of Fish and Wildlife, P.O. Box 3621, Portland, OR. 97283-3621.)

Rondorf, D.W., and K.F. Tiffan, editors. 1994b. Identification of the spawning, rearing and migratory requirements of fall chinook salmon in the Columbia River basin. 1993 Annual Report to Bonneville Power Administration (DOE/BP-21708-3), Contract DEAI79-91BP21708, Portland, Oregon. (Available from Bonneville Power Administration, Division of Fish and Wildlife, P.O. Box 3621, Portland, OR. 97283-3621.)

Rondorf, D.W., and K.F. Tiffan, editors. 1996. Identification of the spawning, rearing and migratory requirements of fall chinook salmon in the Columbia River basin. 1994 Annual Report to Bonneville Power Administration (DOE/BP-21708-4), Contract DEAI79-91BP21708, Portland, Oregon. (Available from Bonneville Power Administration, Division of Fish and Wildlife, P.O. Box 3621, Portland, OR. 97283-3621.)

Skalski, J. R., G. Tartakovsky, S. G. Smith and P. Westhagen. 1994. Pre-1994 Season Projection of Run-Timing Capabilities Using PIT-tag Databases. Center for Quantitative Science, School of Fisheries, University of Washington, Seattle, Washington. Technical Report (DOE/BP-35885-7) to Bonneville Power Administration, Portland, Oregon, Project 91-051, Contract DE-BI79-87BP35885. 67 p. (Available from Bonneville Power Administration, Division of Fish and Wildlife, P.O. Box 3621, Portland, OR. 97283-3621.)

Smith, S. G., W. D. Muir, E. E. Hokersmith, M. B. Eppard, and W. P. Connor. 1997. Passage survival of natural and hatchery subyearling fall chinook salmon to Lower Granite, Little Goose, and Lower Monumental Dams. Pages 1-65 *In* J. G. Williams and T. C. Bjornn, editors. Fall chinook salmon survival and supplementation studies in the Snake and Lower Columbia River Reservoirs, 1995. Annual Report (DOE-BP-10891-4) to Bonneville Power Administration, Portland, Oregon, Project 93-029, Contract 93AI10891 and the U.S. Army Corps of Engineers, Contract E86950141. (Available from Bonneville Power Administration, Division of Fish and Wildlife, P.O. Box 3621, Portland, OR. 97283-3621.)

Stuehrenberg, L. C., A. E. Giorgi, C. W. Sims, J. Ramonda-Powell and J. Wilson. 1986. Juvenile radio-tag study: Lower Granite Dam. Final Res. Rep. (DOE/BP-21237-1) to Bonneville Power Administration, Portland, OR., Project 85-035, Contract DE-AI79-85BP21237. 68 p. (Available from Bonneville Power Administration, Division of Fish and Wildlife, P.O. Box 3621, Portland, OR. 97283-3621.)

Tiffan, K.F., and several co-authors. In preparation-a. Morphological differences between emigrating juvenile spring and fall chinook salmon in the Snake River. A manuscript to be submitted to the Transactions of the American Fisheries Society in 1996.

Tiffan, K.F., and several co-authors. In preparation-b. Marking subyearling chinook salmon to estimate adult contribution in the Columbia River. A manuscript to be submitted to the North American Journal of Fisheries Management in 1996.

Townsend, R. L., P. Westhagen, D. Yasuda and J. R. Skalski. 1995. Evaluation of the 1994 Predictions of the Run-Timing of Wild Migrant Yearling Chinook in the Snake River Basin. Center for Quantitative Science, School of Fisheries, University of Washington, Seattle, Washington. Technical Report (DOE/BP-35885-8) to Bonneville Power Administration, Portland, Oregon, Project 91-051, Contract DE-BI79-87BP35885. 93 p. (Available from Bonneville Power Administration, Division of Fish and Wildlife, P.O. Box 3621, Portland, OR. 97283-3621.)

Townsend, R. L., P. Westhagen, D. Yasuda, J. R. Skalski, and K. Ryding. 1996a. Evaluation of the 1995 Predictions of the Run-Timing of Wild Migrant Yearling Chinook in the Snake River Basin using Program RealTime. Center for Quantitative Science, School of Fisheries, University of Washington, Seattle, Washington. Technical Report (DOE/BP-35885-9) to Bonneville Power Administration, Portland, Oregon, Project 91-051, Contract DE-BI79-87BP35885. 64 p. (Available from Bonneville Power Administration, Division of Fish and Wildlife, P.O. Box 3621, Portland, OR. 97283-3621.)

Townsend, R. L., J. R. Skalski, and D. Yasuda. 1996b Evaluation of the 1995 Predictions of the Run-Timing of Wild Migrant Subyearling Chinook in the Snake River Basin Using Program RealTime. School of Fisheries, University of Washington, Seattle, Washington. Technical Report (DOE/BP-35885-10) to Bonneville Power Administration, Portland, Oregon, Project 91-051, Contract DE-BI79-87BP35885. 21 p. (Available from Bonneville Power Administration, Division of Fish and Wildlife, P.O. Box 3621, Portland, OR. 97283-3621.)

Townsend, R. L.,D. Yasuda, and J. R. Skalski. 1997. Evaluation of the 1996 Predictions of the Run-Timing of Wild Migrant Spring/Summer Yearling Chinook in the Snake River Basin Using Program RealTime. School of Fisheries, University of Washington, Seattle, Washington. Technical Report (DOE/BP-91572-1) to Bonneville Power Administration, Portland, Oregon, Project 91-051, Contract 96BI91572. 30 p. (Available from Bonneville Power Administration, Division of Fish and Wildlife, P.O. Box 3621, Portland, OR. 97283-3621.)